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Study of Characteristics of Cavity Form of Copper Conductor Melted Marks Formed by Short Circuiting

ZHANG Ming[a,b], DI Man[a,b], XIA Da-wei[a,b], ZHANG Ying[a,b], QI Zi-bo[a,b,*]

[a]*Shenyang Fire Research Institution Ministry of Public Security, Shenyang Liaoning 110034,China*
[b]*Key Laboratory for Fire Scene Inquiry & Evidence Confirm of MPS, Shenyang Liaoning 110034, China*

Abstract

By using metallurgical analysis software to analyze cavity form of copper conductor melted marks formed by short circuiting in normal atmosphere and fire atmosphere, found out the corresponding relationship between characteristic parameters and melted marks properties, proposed quantitative criterion, so as to provide scientific bases for identifying fire cause.

Key words: melted mark; cavity form; characteristic parameter

1. Introduction

The work of fire evidence identification is that professional accreditation bodies using technical methods and specialized equipment to test the evidences which detected from fire point, give the identification conclusion after integrated decision, find out the fire origin and fire lighter, and arrive at exact cause of the fires. However, existing mature technical methods for electrical fire evidence, such as macroscopic method and metallographic analysis method, all are qualitative techniques; and in the process of the formation of traces, affected by many factors, such as temperature, atmosphere and work experience. So how to apply quantitative methods to solve the gray area not yet identified, to be a need to solve the technical problems.

2. Cavity formation mechanism

The cavity formation mainly affected by the environmental atmosphere and environmental temperature.

* Corresponding author: Tel.: +86-24-31535752; fax: +86-24-31535752.
E-mail address: zhangming@syfri.cn.

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2.1. Environmental atmosphere

Gas dissolved in the metal is usually divided into three stages: adsorption, dissociation, diffusion. Dissolution rate depends on the gas diffusion rate, the higher the temperature of the metal, gas and metal in contact longer, the dissolved gas the more. When the liquid copper fell from 1300℃ to 1083℃ the melting point of pure copper, the solubility decreased from 10.2% to 9.4%-5.17%, solidification decreased to 1.9% after the solidification. That is, when the liquid copper from the high temperature cooled to freezing temperature, and then crystallization is completed, there will be about 8cm^3 gas escaped from the solid copper for per 100 grams. If the cooling rate is slow enough, the escaping gas were relatively high; and if the cooling rate is fast, the shorter solidification time is, the more gas trapped in the metal.

2.2. Environmental temperature

Primary short circuited melted mark (**PSM**) formed in the normal atmosphere and lower ambient temperature, cooling speed is fast, and solidification is short. Although the more gas that not escape which trapped into the melted marks, because of the little combustion products, the cavities are always few and smaller.
Second short circuited melted mark (**SSM**) formed in fire atmosphere and high fire scene temperature, the solidification process is longer. The more gas escape from melted marks, but in this fire atmosphere, there are lots of dust, impurities, various combustion products and steam, will also be entered in the liquid copper, so the cavities are always more and bigger.
The volume of metal solution changes before and after solidification, the shrinkage rate is 3% to 5%. So after arc interrupted, although the shell of liquid metal freeze, within the liquid metal is still expanding. When the internal liquid metal solidified, the part of the contraction and the lack of supplement, it does not take such a big volume case. Both **PSM** and **SSM** in addition to cavities exist inside, but there is also some shrinkage.
The shrinkage formation mechanism of **PSM** and **SSM** is the same, but the atmosphere conditions and temperature conditions are different. So the cavities of **PSM** are smaller and few, but **SSM**' are bigger and more.

3. Sample preparation and analysis

Samples for this study are copper conductor melted marks originated in simulation testing, including 1.0mm^2 single-strand copper wires and 1.0mm^2 multi-stranded copper wires. The samples are prepared according to characteristic of copper conductor melted marks formed in electrical fires, melted marks are formed when copper conductors in simulation testing devices are energized with powerful current and short circuited in normal atmosphere and fire atmosphere. Observe appearance patterns through video microscope (HIROX KH-7700), view microstructure through microscope (Olympus PMG-3), analysis cavity characteristic parameters through metallurgical analysis software (Olycia M3).
The shapes of cavity inside melted marks are irregular, such as sphere, ellipsoid and other irregular three-dimensional shape which exist alone or stacking mode. Represent characteristics of whole cavity form with longitudinal 1/3 to 1/2 parts of the plane projection (metallographic photos), analyze the characteristic parameters of cavities through metallurgical analysis software, such as quantity, roundness, area, roughness, maximum calipers diameter, etc. Before analysis the cavity characteristic parameters, the cavities presented in the metallographic photos, need to be processed, screened, detailed steps are as follows:
(1) Stitch the metallographic photos;
(2) Select the melted region;
(3) Convert to binary photos, and separate the cavities, shown as figure 1;
(4) In statistical calculations.

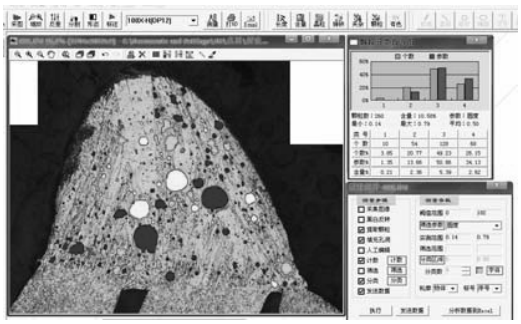

Fig. 1. Processed metallographic photo

4. Results and discussion

4.1. Cavity quantity

Cavity quantity is the number of cavities in the melted region. Detailed date is shown as in Table 1. As seen from the comparing situation, both of the cavity quantity statistical data of Single-strand and Multi- strand copper wire are stochastic and irregular. It proves that the fire atmosphere and ambient temperature do not matter the quantity of cavities.

Table 1. Cavity quantity of Single-strand and Multi- strand copper wire melted mark

Quantity		Single-strand copper wire	Multi-strand copper wire
PSM	most	500	434
	lest	57	47
	average	221.4	206
SSM	most	363	819
	lest	73	216
	average	216.6	361.3

4.2. Cavity maximum calipers diameter

Cavity maximum callipers diameter: to consider the cavity size. Detailed date is shown as in Table 2. As seen from the comparing situation, both of single-strand copper wire and multi-stand copper wire, the **SSM** are bigger than **PSM**. For the purposes of single-strand copper wire, the largest amount zone of **PSM** is 4-16 (45%-65%), whereas 2-4 (20%-30%) has the second. But the **SSM** followed by 4-16 (40%-55%) and 16-64 (25%-35%). So the **PSM** and **SSM** are obvious in the second largest amount zone. For multi-stand copper wire, both of **PSM** and **SSM** had the same largest amount zone 4-16. But the other zones of **PSM** are equal, 2-4 and 0-2 are the second zone of **SSM**. It proves that the cavity size is larger in fire atmosphere and fire temperature.

Table 2. Cavity maximum calipers diameter of Single-strand and Multi- strand copper wire melted mark

Maximum callipers diameter		Single-strand copper wire	Multi-strand copper wire
PSM	minimum (μm)	0.18	1.35
	maximum (μm)	189.03	85.99
	the largest amount of zone (%)	4-16 (45%-65%)	4-16 (45%-70%)

	the second largest amount of zone (%)	2-4 (20%-30%)	--
SSM	minimum (μm)	1.20	0.18
	maximum (μm)	687.19	581.75
	the largest amount of zone (%)	4-16 (40%-55%)	4-16 (50%-60%)
	the second largest amount of zone (%)	16-64 (25%-35%)	0-4 (15%-20%)

4.3. Cavity area

Study melted mark cavities from volume size. Detailed date is shown as in Table 3. Both of single-strand copper wire and multi-stand copper wire, the area characteristic parameters of **PSM** are larger than **SSM**, such as the largest cavity area percentage of all the cavities area, the largest cavity area percentage of melted region area and all the cavities area percentage of all melted region area. And **PSM** have the same largest amount of zone 1-10, but the percentage is different. And **SSM** are mainly concentrated in zone 10-100 and 1-10. Then the fire atmosphere plays an important role in the size of melted mark cavity.

Table 3. Cavity area of Single-strand and Multi- strand copper wire melted mark

	Area	**Single-strand copper wire**	**Multi-strand copper wire**
PSM	minimum (μm^2)	0.4	0.8
	maximum (μm^2)	22195.29	3986.76
	the largest amount of zone (%)	1-10 (45%-50%)	1-10 (35%-60%)
	the second largest amount of zone (%)	10-100 (25%-40%)	10-100 (30%-50%)
	the largest cavity area percentage of all the cavities area (%)	10%-20%	10%-25%
	the largest cavity area percentage of melted region area (%)	0.54%-4.87%	0.54%-4.87%
	all the cavities area percentage of all melted region area (%)	4.10%-9.97%	0.85%-8.90%
SSM	minimum (μm^2)	0.6	2.01
	maximum (μm^2)	136533.7	104991.28
	the largest amount of zone (%)	10-100 (35%-55%)	1-10 (20%-55%)
	the second largest amount of zone (%)	100-1000 (20%-30%)	10-100 (20%-50%)
	the largest cavity area percentage of all the cavities area (%)	20%-55%	20%-60%
	the largest cavity area percentage of melted region area (%)	22.56%-35.12%	0.39%-22.09%
	all the cavities area percentage of all melted region area (%)	42.27%-58.42%	9.40%-38.69%

4.4. Cavity roundness

Cavity roundness: calculated as shown in

$$Rd = \frac{c^2}{4\pi S} \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Where *c* is the outline perimeter of cavity, *S* is the area of cavity. The value is closer to 1, indicating more circular. Detailed date is shown as in Table 4. As seen from the comparing situation, both of single-strand copper wire and multi-stand copper wire, the **PSM** is more circular than **SSM**. For the purposes of single-strand copper wire, both of **PSM** and **SSM** have the same largest amount of zone and percentage, which are 0.5-0.6 (20%-35%), discrimination is not obvious. And multi-stand copper wire, the largest amount zone of **PSM** is 0.5-0.7, but the **SSM** is 0.3-0.5. So we can see that the cavities formed in cleaner atmosphere and lower temperature is more circular.

Table 4. Cavity roundness of Single-strand and Multi- strand copper wire melted mark

	Roundness	Single-strand copper wire	Multi-strand copper wire
PSM	minimum	0.05	0.09
	maximum	1.00	0.99
	the largest amount of zone (%)	0.5-0.6 (20%-35%)	0.5-0.6 (25%-50%)
	the second largest amount of zone (%)	0.6-0.7 (20%-30%)	0.6-0.7 (15%-25%)
SSM	minimum	0.09	0.05
	maximum	0.99	0.99
	the largest amount of zone (%)	0.5-0.6 (20%-35%)	0.4-0.5 (20%-30%)
	the second largest amount of zone (%)	0.4-0.5 (20%-30%)	0.3-0.4 (15%-25%)

4.5. Cavity roughness

The ratio of outline perimeter and convex perimeter, the bigger value is, the smoother surface cavity had. Detailed date is shown as in Table 5. For the purposes of single-strand copper wire, the largest amount zone of **PSM** is 1.1-1.2(55%-50%), whereas 1.2-1.3(20%-30%) has the second. But the **SSM** followed by 1.2-1.3 (25%-35%) and 1.1-1.2(25%-30%). So the **PSM** and **SSM** are obvious in the second largest amount zone. For multi-stand copper wire, the largest amount zone of **PSM** and **SSM** are 1.1-1.2 (35%-45%) and 1.2-1.3 (25%-35%). And the second of **PSM** is 1.2-1.3 (25%-35%), but the **SSM** are 1.1-1.2 (15%-25%) & 1.3-1.4 (15%-25%). So we can consider that the cavity surface is smooth in the absence of fire atmosphere and fire temperature.

Table 5. Cavity roughness of Single-strand and Multi- strand copper wire melted mark

	Roughness	Single-strand copper wire	Multi-strand copper wire
PSM	minimum	1	1
	maximum	2.69	2.19
	the largest amount of zone (%)	1.1-1.2 (35%-50%)	1.1-1.2 (35%-45%)
	the second largest amount of zone (%)	1.2-1.3 (20%-30%)	1.2-1.3 (25%-35%)
SSM	minimum	1	1
	maximum	2.54	3.52
	the largest amount of zone (%)	1.2-1.3 (30%-35%)	1.2-1.3 (25%-35%)
	the second largest amount of zone (%)	1.1-1.2 (25%-30%)	1.1-1.2 (15%-25%) & 1.3-1.4 (15%-25%)

5. Conclusions

(1) Fire atmosphere and fire temperature have a crucial import on cavity form characteristic parameter of copper conductor melted marks formed by short circuiting, such as roundness, area, roughness and maximum callipers diameter, but it does not matter with cavity quantity.
(2) Both single-strand and multi-strand copper wire, the cavity form characteristic of **PSM** is basically consistent to **SSM**.
(3) For single-stand copper wire, **PSM** and **SSM** can be identified by the characteristic parameters, including the largest amount zone of area, the largest cavity area percentage of all the cavities area, the largest cavity area percentage of melted region area, all the cavities area percentage of all melted region area, roundness, roughness.
(4) For multi-stand copper wire, the characteristic parameters of roundness and all the cavities area percentage of all melted region area can identify **PSM** and **SSM**, and roughness and the largest cavity area percentage of all the cavities area can be used as reference data, but the largest amount zone of area and the largest cavity area percentage of melted region area are no reference value.

References

[1] Wang Xiqing, Han Baoyu, Di Man. Guidelines for Electrical Fire Scene Investigation and Identification Technique. Publishing House of Liaoning University; 1990.

[2] Technical Identification Method of Electrical Fire Cause. China national standard GB16840.1to 4;1997.

[3] Di Man, Zhang Ming. Statistics and Analysis of Electrical Fires in 1993-2002 in the Nation. Building Electrical & Intelligent System; 2004(09), p. 103–111.